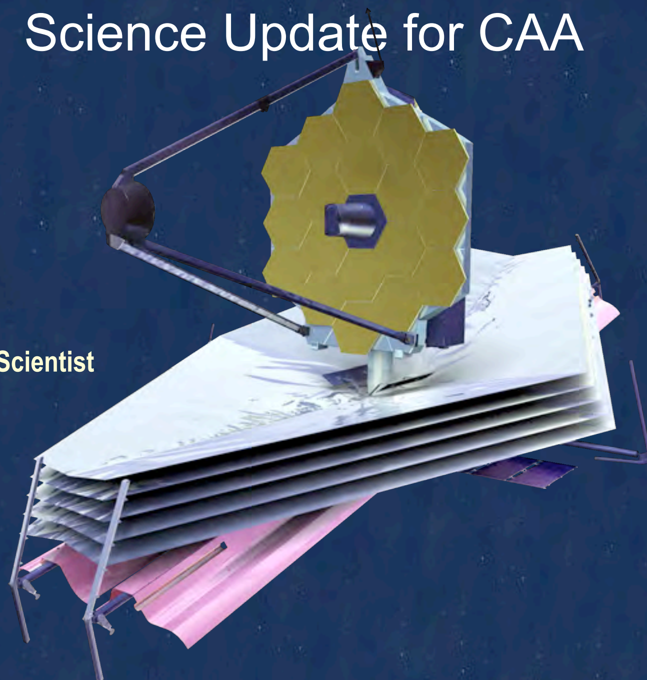
James Webb Space Telescope (JWST)

Science Update for CAA



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JWST Senior Project Scientist
NASA/GSFC
May 20, 2006

JWST Level 0 Requirements (why we're doing all this)

- Replace HST as general community space observatory - by 2013, HST, Chandra, and Spitzer are old or dead, and SOFIA is smaller and in air
- Do what only NASA can do - big, powerful, wavelengths not visible from ground, worthy of the taxpayers' dollars
  - We already have HST and Spitzer
    - We're at the limits of what they can do
    - Must do much better
  - Strategic planning said, get biggest possible segmented mirror, as next step for future missions
- Next great scientific opportunity is near-mid IR, per HST & Beyond report of 1995 - no change since 1995
- This is why JWST is #1 priority

JWST Mission Requirements

Defined in section 5 of the JWST Program Plan (JWST-PLAN-000633)

Established during the JWST study phase by the study science team (ASWG) and NASA HQ.
Recently revised to incorporate recommendations of the Science Assessment Team (SAT).

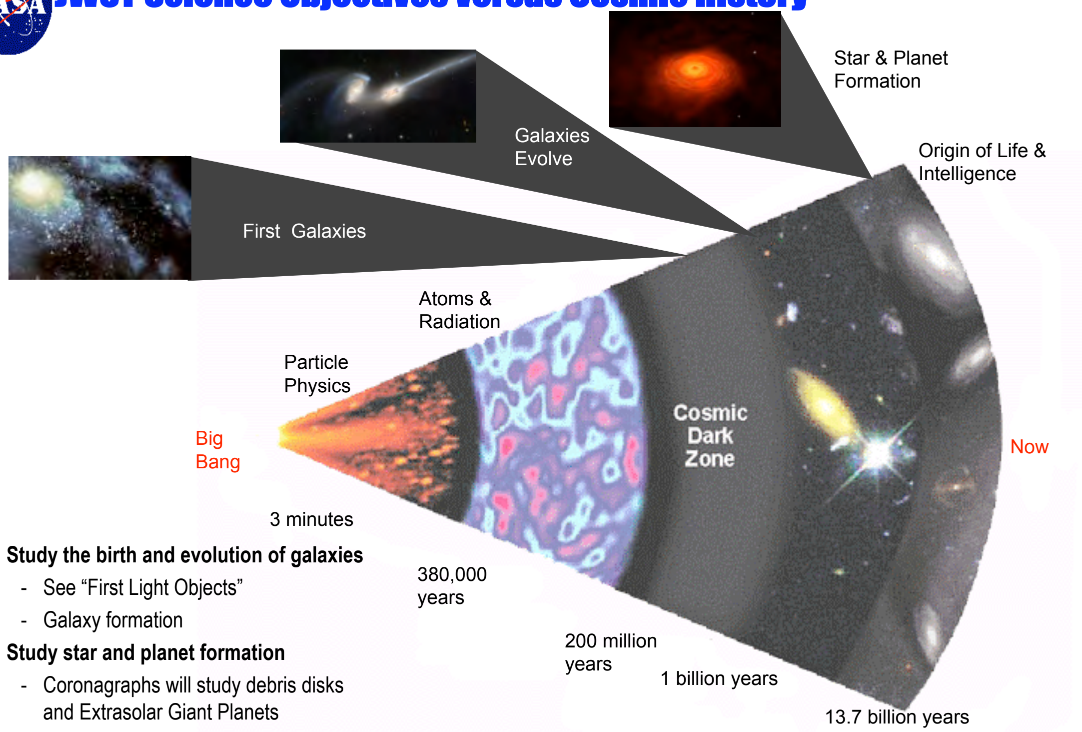
	Baseline Science Requirements	**Minimum Science Requirements**
Density of Galaxies	Measure the space density of galaxies to a 2 micrometer flux density limit of 1.0×10^{-34} $Wm^{-2}Hz^{-1}$ via imagery **within the 0.6 to 27 micrometers spectral band** to enable the determination of how this density varies as a function of their age and evolutionary state.	Measure the space density of galaxies to a 2 micrometer flux density limit of 1.0×10^{-34} $W m^{-2}Hz^{-1}$ via imagery **within the 1.7 to 10 micrometers spectral band** to enable determination of how this density varies as a function of their age and evolutionary state.
Spectra of Galaxies	Measure the spectra of at least **2500 galaxies** with spectral resolutions of approximately 100 (**over 0.6 to 5 micrometers**) and 1000 (**over 1 to 5 micrometers**) and to a 2-micrometer emission line flux limit of 5.2×10^{-22} Wm^{-2} to enable determination of their redshift, metallicity, star formation rate, and ionization state of the intergalactic medium.	Measure the spectra of at least **1000 galaxies** with spectral resolutions of approximately 100 (**over 1.7 to 5 micrometers**) and 1000 (**over 1.7 to 5 micrometers**) and to a 2-micrometer emission line flux limit of 5.2×10^{-22} Wm^{-2} to enable determination of their redshift, metallicity, star formation rate, and ionization state of the intergalactic medium.
Physical & Chemical Properties of Young Stellar Objects	Measure the physical and chemical properties of young stellar objects, circumstellar debris disks, extra-solar giant planets, and Solar System objects via spectroscopy, and imagery within the **0.6 to 27 micrometers spectral band** to enable determination of how planetary systems form and evolve.	Measure the physical and chemical properties of young stellar objects, circumstellar debris disks, extra-solar giant planets, and Solar System objects via spectroscopy, and imagery within the **1.7 to 10 micrometers spectral band** to enable determination of how planetary systems form.
Observing Time	Enable, within a **5-year mission**, **a total observing time of at least 1.1×10^{8} seconds** on targets located at any position on the celestial sphere.	Enable a **total observing time of at least 5.5×10^{7} seconds** on targets located at any position on the celestial sphere.

Reference: Question 3-9

Scientific Developments since November 2005

- **2006, new WMAP results confirm first results, early first light, predicted redshift for reionization is easier to reach (z ~ 12 vs. 17)**
- **2006, planet transits recognized as serious JWST target, including Earthlike planets around M dwarf stars**
- **Science Assessment Team recommendations implemented**
  - Relax performance < 1.7 microns, etc.
- **Scientific Capabilities and Objectives document**
  - "James Webb Space Telescope" manuscript accepted for publication in *Space Science Reviews* (J. Gardner, Deputy Senior Project Scientist, and the SWG)
  - http://www.jwst.nasa.gov/resources/files/JWST_SSR_JPG.pdf

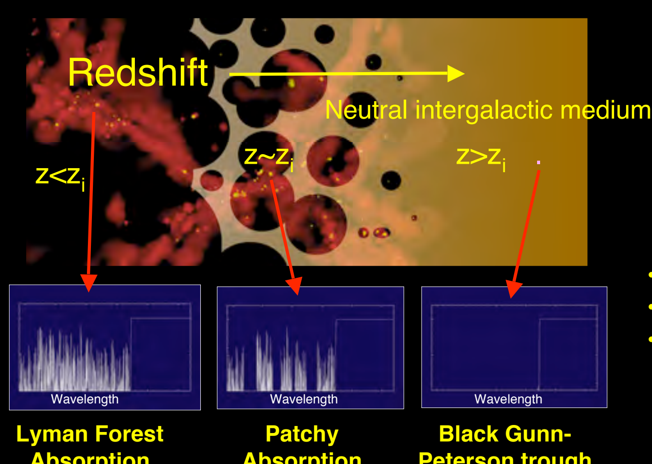
JWST Science Objectives versus Cosmic History



- **Study the birth and evolution of galaxies**
  - See "First Light Objects"
  - Galaxy formation
- **Study star and planet formation**
  - Coronagraphs will study debris disks and Extrasolar Giant Planets
  - Transit spectroscopy of planets

End of the dark ages: first light and reionization

- What are the first galaxies (beyond those seen by Hubble at z = 6)?
- When did reionization occur?
  - Once or twice?
- What sources caused reionization?



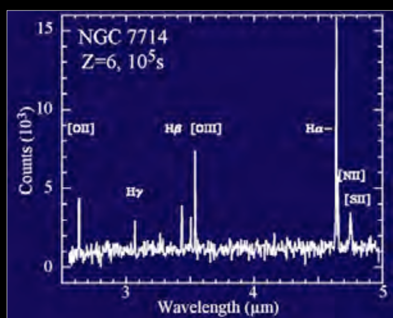
Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

- Ultra-deep field
- Spectrum of distant quasars
- Studies of faint galaxies

The assembly of galaxies

- Where and when did the Hubble Sequence (of galaxy shapes) form? (probably after redshift 6)
- How did the heavy elements form?
- What theories explain the shapes and histories of galaxies?
- What about star-forming galaxies and giant black holes?

Galaxies in GOODS Field



- Wide-area imaging survey
- Spectroscopy of thousands of galaxies
- Targeted observations of extreme galaxies

Birth of stars and protoplanetary systems

- How do clouds collapse?
- How does environment affect star formation?
  - Vice-versa?
- What is the boundary between low-mass stars and giant planets?

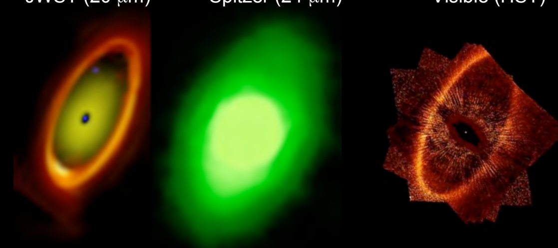
The Eagle Nebula
as seen in the infrared

Stars in dust disks in Orion (proplyds)

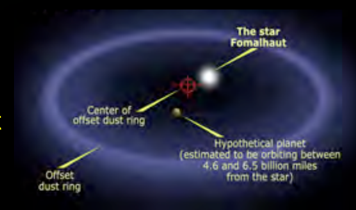
- Imaging of molecular clouds
- Survey “elephant trunks”
- Survey star-forming clusters

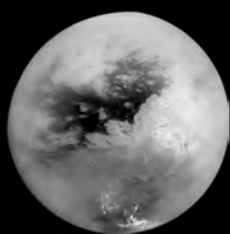
Planetary systems and the origins of life

- How do planets form?
- Are exosolar systems like our own?
- How are habitable zones established?
- Detection of planets via debris disks
  - Directly image very young planets
  - Indirectly detect planets via their footprints in debris disks



Fomalhaut





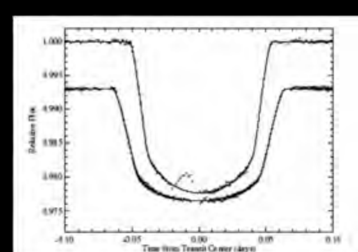
Titan

- Exosolar giant planets
  - direct imaging by blocking star's light
- Spectra of organic molecules in disks, comets and Kuiper belt objects in outer solar system
- Atmospheric composition of exosolar planets
  - Observe transits of planets

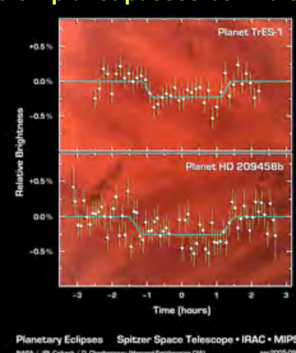
JWST characterizes transiting planets

- Transit light curves
  - Kepler extrasolar giant planets

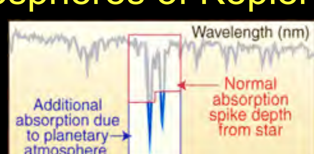
HST: planet transits star



Spitzer: planet passes behind star



- Transit Spectroscopy
  - Terrestrial planets around M stars
  - Atmospheres of Kepler giant planets



Confirmation of Kepler Planet Candidates

- Examples of JWST S/N = 35 transit detections
  - Earth-sized planet orbiting a sun-like star at 1 AU at Kepler star distances (transit time 13h, d=300 pc)
  - Earth-size moon around HD209458b (transit time 3 h, d=47 pc)

1. Aperture is key (Det. Lim. regime)

- S/N ~ D^2 ~ Collecting Area

  JWST 25 m^2 collecting area

  HST 4.5 m^2 collecting area (JWST has 6x more)

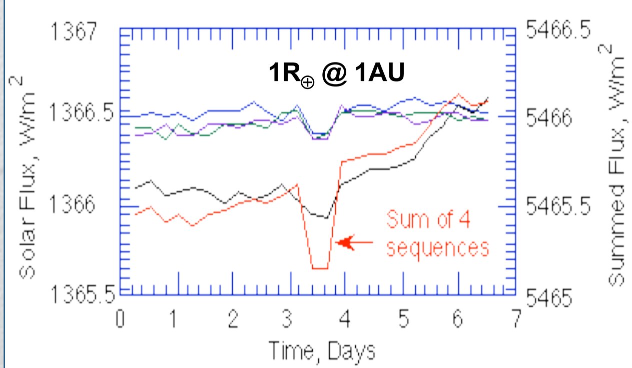
  Spitzer 0.57 m^2 (JWST 40x)

  Kepler 0.71 m^2 (JWST 30x)

2. Space is stable

   High dynamic range photometry

   $10^{-4} – 10^{-5}$ possible



The four sections of a simulated light curve containing the transits of an Earth-size planet (1.0 R_e) are folded at the correct period, with the sum shown in red. The presence of the transit is unmistakable.

http://www.kepler.arc.nasa.gov/

Courtesy: Seager (2005) & Astrobiology and JWST (contributed by R. Gilliland)

Each HST Instrument Is the Equivalent of an Explorer or Mid-Ex Mission

Instrument	Class	Year Flown	Cost ($M) [1]	P.I. or Science Team Leader
WFPC1	P.I.	1990	196.5	J. Westphal, Cal Tech
FOS	P.I.	1990	110	R. Harms, UCSD
FOC	Facility	1990	N/A	F. Macchetto, ESA
GHRS	P.I.	1990	114.8	J. Brandt, GSFC
HSP	P.I.	1990	25.5	R. Bless, U. Wisconsin
FGS/ Astrometry	Facility	1990, 1997	N/A	W. Jefferies, U. Texas
WFPC2	Facility	1993	158.2	J. Trauger, JPL
NICMOS	P.I.	1997	156.2	R. Thompson, U. Arizona
STIS	P.I.	1997	185.5	B. Woodgate, GSFC
ACS	P.I.	2002	78.4	H. Ford, JHU
COS	P.I.	2007?	81.5 [2]	J. Green, U. Colorado
WFC3	Facility	2007?	126.2 [2]	R. O'Connell, U. Virginia

1. Cost escalated to FY 2006 dollars, includes instrument development only. Funding for post-launch science team (GTO) investigations book-kept separately.

2. Includes Full Cost Accounting beginning in FY'04.

The Importance of Flagship Missions Was Emphasized in the 2000 NAS/NRC/CAA Report "Federal Funding for Astronomical Research"

"The continuing growth in funding for astronomy in the 1980's and 1990's has been largely the result of the success of NASA's space science program, in particular the launch of NASA's Great Observatories and several midsized facility-class satellites."

"HST GO and GTO funding currently represents ~30% of the total direct grant funding to the U.S. astronomical community. Much of this money funds Ph.D. astronomers, graduate students , and institutional technical support staff...."

"Most important is that a significant fraction of the support for the youngest members of the field comes from such missions. The impact [of loss of a major mission] on the youngest astronomers, such as those supported by CGRO, Hubble, and Chandra fellowships and those supported by the R&A funds for such missions, would be disproportionately large and would significantly alter the future of the field."

JWST in Context

- Enormous scientific breakthroughs possible
- Next logical step after HST
  - 7x larger collecting area, optimized for infrared that HST can't see
  - Thousands of times faster observations
  - Extends science & international partnership
- Builds on Spitzer IR heritage
  - 50 x collecting area, much bigger & better detectors
  - Angular resolution of HST
- Synergy with planned giant ground-based telescopes
- Essential part of planet program - transits, coronography, dust disks, solar system
- Technology legacy for future missions - detectors, optics, wavefront sensing, adjustment, deployment, coolers

Summary

- Top priority in astronomy and astrophysics, per National Academy of Sciences and JWST Science Assessment Team
- Revolutionary paradigm-shifting science in 4 major areas:
  - First light
  - Galaxy formation
  - Star and planet formation
  - Planetary systems and conditions for life
- Shared facility enables university science
  - Provide data to HST and Spitzer users
  - ~ 200 projects each year
  - Archive and observing grants planned for ~ $250M in 10 year life
- Risks are well managed
  - Cost, schedule, technology, science
- Every reason to expect that public will take ownership of JWST just as with HST

JWST Science Backup Charts

Brief History of JWST Science

- 1989 conference, wanted UV telescope much larger than HST
- 1990, HST launched
- 1995, HST & Beyond report, wanted IR telescope > 4 m, optimized for 1-5 microns; project study started; objectives from first light to planets
- 1996, 8 m baselined (50 m^2)
- 2002, descoped area by half to 25 m^2; accepted by CAA
- 2002, Northrop Grumman selected with 29.7 m^2
- 2003, Spitzer Space Telescope launched, showed very early universe bright in IR, observed dust disks around stars, proved need for mid IR on JWST
- 2003, WMAP showed universe lit up very early, redshift ~ 17, moved the goal for the First Light studies to much longer wavelengths
- 2003, JWST descoped to 25 m^2, smaller instruments; selected beryllium mirrors
- 2005, deleted tunable filter module, descoped performance at wavelengths < 1.7 microns overlapping with GSMT on ground, relaxed contamination requirements, per Science Assessment Team
- 2006, new WMAP results confirm first results, early first light, redshift easier to reach ($z \sim 12$)
- 2006, planet transits recognized as major JWST target, including Earthlike planets around M dwarf stars

JWST Science Assessment Team, 2005

- "The international scientific community is unanimous in regarding the James Webb Space Telescope as the highest priority facility for the US and the international community to advance astrophysical understanding"
- "…the case for the telescope and its unique capabilities has grown in strength and astronomical significance."
- "JWST is the only facility planned for the next two decades with the resolution and sensitivity in the thermal infrared needed to address the nature of First Light directly."
- "[JWST]… is positioned to uniquely contribute to the great question: "Throughout the universe, how common are the life generating processes [that] took place almost 4 billion years ago in our solar system?"
- "JWST will therefore be our opportunity to open the window wide to the nature of the fantastically diverse extrasolar planets …"
- "JWST offers the only IR mission capable of studying extra solar planetary systems this decade"
- Ground-based capabilities are growing at wavelengths < 1.7 μm with plans for GSMT, so relax performance requirements for JWST where there is overlap

COBE Lessons Learned for JWST

- It's the detectors, stupid!
  - Early investment in upgrades to HST & Spitzer detectors
  - Development of cryogenic ASICs to limit noise pickup
- Parts and materials properties must be measured for the exact designs, materials, adhesives, and joining processes used
  - Extensive test programs, TRL-6 by January 2007
- Contamination control to unknown requirements is infinitely expensive
  - Relaxed contamination requirements per SAT review
  - Detailed stray light and contamination modeling being done
  - Stray light is not dominated by dust scattering but by unwanted light getting past baffles, so more cleanliness doesn't help much
- Almost all cryo tests have to be repeated
  - Use pathfinders and Engineering Test Units to find problems early and work out the procedures before risking flight hardware
  - Plan for very long integration and test program with lots of contingency
- Reworking software from one computer system to another is very costly
  - Provide single system from the beginning